New availability of near real-time Arctic sea ice thickness results from IceBridge and CryoSat-2 data

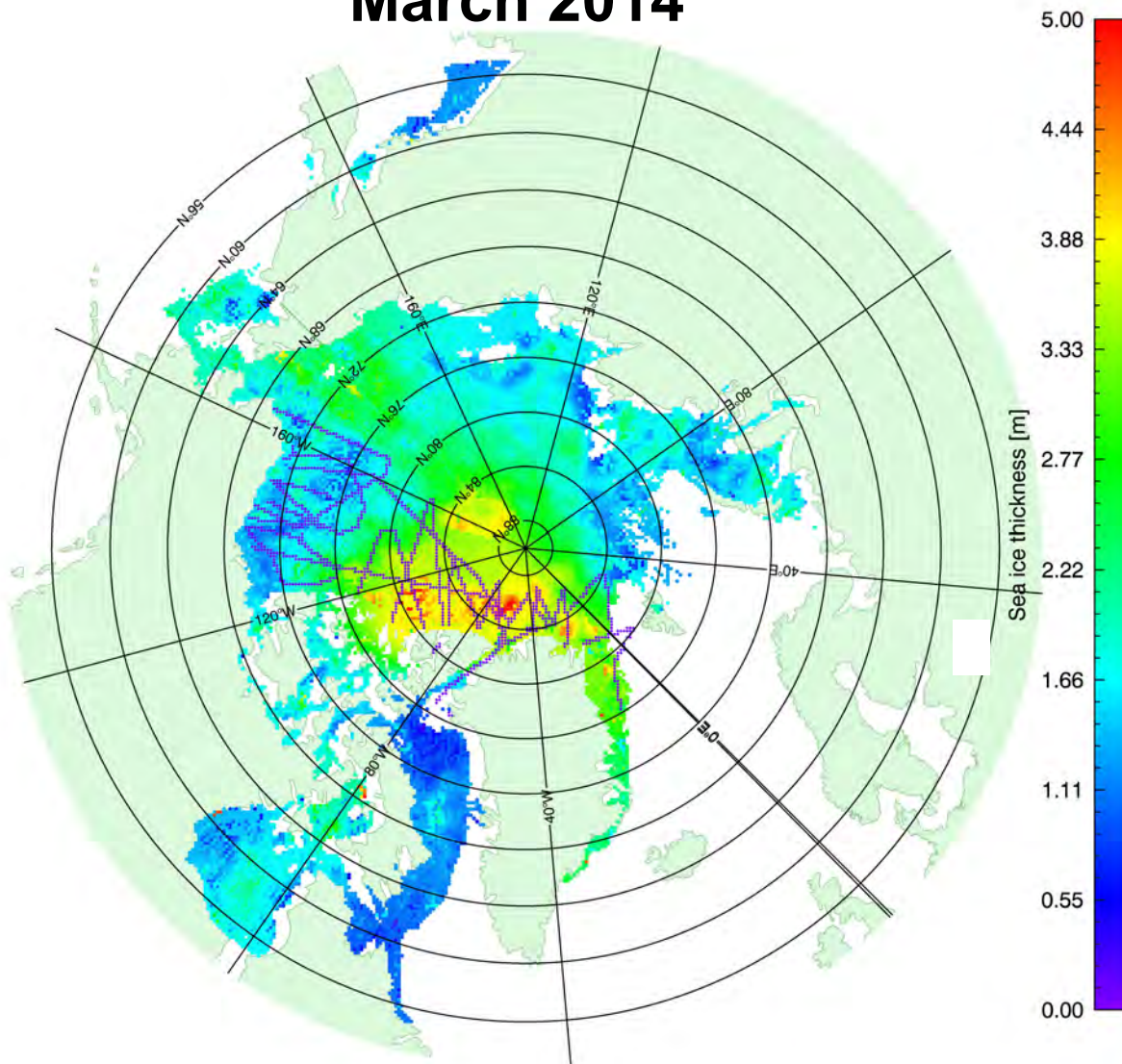Nathan Kurtz, Code 615, NASA GSFC

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Figure 1: Arctic sea ice thickness for March 2014 derived from CryoSat-2 radar altimetry data, SSM/I passive microwave data, and Operation IceBridge snow radar data. The thickness of the sea ice is an indication of the health of the sea ice pack and is a primary indicator of the ability of sea ice to survive the summer melt season. Thick ice can be seen in the perennially covered regions of the Arctic Ocean north of Greenland and Canada, while thinner seasonal ice surrounds the perennial ice regions and extends outward from the Arctic Ocean. The dashed purple lines in the central Arctic Ocean are the flight tracks of the Operation IceBridge campaign which was collecting data during the same time period enabling quality assurance of the new CryoSat-2 derived sea ice thickness data set.

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Abstract: Observations of Arctic sea ice thickness have been taken for more than five decades and have shown a two-fold decrease in mean sea ice thickness. Past observations were made with spatially and temporally limited submarine sonar data. However, recent technological advances now allow for sea ice thickness to be observed over the entire Arctic basin from satellite instruments. A new method for the retrieval of sea ice freeboard and thickness from the currently operational CryoSat-2 satellite radar altimeter has been developed. These data have been compared to airborne data from NASA's Operation IceBridge campaign showing broad-scale consistency in the measurements from different sensors. Less than two months after data collection, sea ice thickness data for March 2014 from both CryoSat-2 and IceBridge have been provided to the National Snow and Ice Data Center (www.nsidc.org) and are publicly available for download. The new availability of these data sets enables long-term climatological comparisons to be made with historic data sets as well as provides information on the current state of the Arctic sea ice pack for use in seasonal sea ice forecast models.

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Data Sources: Surface elevation is derived from the European Space Agency's CryoSat-2 radar altimeter. The surface elevation is used to retrieve the height of the ice surface above the water level, termed sea ice freeboard. Snow depth on sea ice is derived from a combination of passive microwave data from SSM/I and the Operation IceBridge snow radar. The algorithms involved in the retrieval of surface elevation and snow depth were developed at NASA/GSFC. Together, these data sets allow for sea ice thickness to be determined using Archimedes' principle.

Both the CryoSat-2 and Operation IceBridge sea ice thickness data sets are available for public download at:
http://nsidc.org/data/docs/daac/icebridge/evaluation_products/sea-ice-freeboard-snowdepth-thickness-quicklook-index.html.

Technical Description of Image:
Figure 1: Average Arctic sea ice thickness for March 2014. A new method for the retrieval of surface elevation data from the CryoSat-2 satellite has been developed and used to derive sea ice freeboard. Snow depth on sea ice from a combination of passive and active microwave data has been derived using optimal interpolation. Using nominal densities for snow, ice, and water, the thickness of the ice was then determined. The data were compared with airborne measurements from Operation IceBridge to ensure consistency, showing a mean difference of less than 10 cm.

Scientific significance: Arctic sea ice has been undergoing rapid change in recent years with observations of sea ice extent and thickness showing continual decline. The thickness of the ice cover and snow cover is a primary indicator of the ability of sea ice to survive the summer melt-season. Sea ice thickness is also a key parameter for evaluating and improving predictive models of conditions in the Arctic Ocean over seasonal (2-3 months) to decadal time scales (>10 years). The availability of these new and quickly produced sea ice thickness data sets will allow for improved seasonal to decadal scale analyses of changes in Arctic sea ice to be made.

Relevance for future science and relationship to Decadal Survey: The new Arctic sea ice thickness data set is very relevant to NASA's mission to better understand the Earth's climate system and the decadal survey. These new data products complement broader efforts by the sea ice community to integrate observations of sea ice conditions to provide a unified source of information for easy analysis. The combined data products seek to reconcile the sea ice thickness data sets from radar and laser altimetry, providing a bridge between ICESat, IceBridge, CryoSat-2, and the future ICESat-2 satellite mission to be launched in 2017.
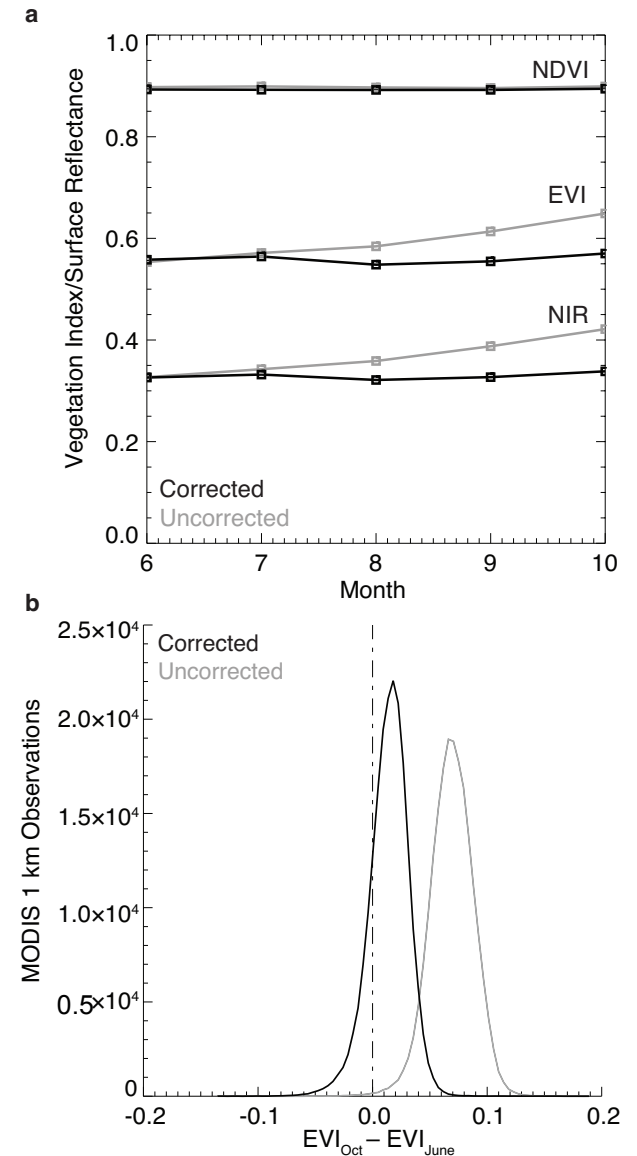
Consistent canopy structure and reflectance properties of Amazon forests during the dry season

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Figure 1: Example MODIS observation in the principal plane, including the hot-spot effect over Amazon vegetation

Figure 2: The apparent seasonal green up of Amazon forests in MODIS data results from changes in sun-sensor geometry between the June solstice and September equinox. Correcting for principal plane effects eliminates seasonal changes in near-infrared surface reflectance (NIR, and therefore EVI), consistent with independent measurements of forest structure from ICESat-GLAS lidar.

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Reference: Morton DC, Nagol J, Carabajal C, Rosette J, Palace M, Cook BD, Vermote E, Harding D, North P (2014). Amazon forests maintain consistent canopy structure and reflectance during the dry season. Nature 506, 221-224 (05 February 2014).

Data Sources: This study analyzed seasonal changes in Amazon forest canopy structure and reflectance properties using surface reflectance data from the Terra and Aqua MODIS sensors and independent lidar data from ICESat-GLAS. MODIS data were normalized for changes in sun-sensor geometry using a monthly, per-pixel inversion of the bidirectional reflectance distribution function (BRDF) parameters. Lidar data were analyzed as apparent reflectance (a ratio of laser output and return energies at 1064 nm) and lidar metrics corresponding to the distribution of energy within the waveform. A sophisticated 3D radiative transfer mode was used to generate study hypotheses for expected changes in passive optical and lidar data from seasonal variability in leaf reflectance, litter reflectance, leaf area, and sun-sensor geometry. The modeled Amazon forest was constrained using field measurements of Amazon forest characteristics from NASA's Large-scale Biosphere Atmosphere Experiment in Amazonia (LBA).

Technical Description:
Image: The Terra MODIS image of the Amazon region (October 27, 2002) highlights characteristic features of MODIS observations in the principal plane, including the hot-spot effect in the backscatter direction over Amazon forests. (NASA Earth Observatory, http://earthobservatory.nasa.gov/IOTD/view.php?id=83048, http://www.nasa.gov/content/goddard/nasa-study-points-to-infrared-herring-in-apparent-amazon-green-up/).

Figure 1. MODIS data, normalized for seasonal changes in sun-sensor geometry, indicate consistent canopy structure and reflectance properties of Amazon forests during the dry season.

Figure 2: a) Seasonal changes in MODIS data with (black) and without (gray) a correction procedure to normalize sun-sensor geometry during the dry season (June-October). Near-infrared reflectance (NIR) and the Enhanced Vegetation Index (EVI) are particularly sensitive to artifacts from seasonal changes in sun-sensor geometry, while the normalized difference vegetation index (NDVI) is more robust to seasonal changes in sensor geometry. *b)* Per-pixel changes (October-June) in EVI data with (black) and without (gray) normalization of sun-sensor geometry.

Scientific significance: Our study has three main scientific contributions: 1) consistent leaf reflectance and leaf area during the dry season suggests that 3D structure plays a key role in changing light availability in Amazon forests, driven by seasonal variability in self-shading between the June solstice and September equinox. 2) Increases in MODIS EVI over Amazon forests during drought periods may be explained by lower cloud cover during drought years —increasing the likelihood of clear observations when the MODIS sensor is in the principal plane. 3) ICESat-GLAS lidar data in this study indicate a stable underlying pattern of forest structure. Further investigation of these patterns can shed light on the organizing principles of tropical forest structure across the Amazon basin.

Relevance for future science and relationship to Decadal Survey: The remote sensing artifact that generates an apparent green up of Amazon forests also plagues in situ, airborne, and space-based analyses of phenology and vegetation productivity in other tropical, temperate, and boreal biomes. Whether the impact of seasonal changes in sun-sensor geometry leads to an apparent increase or decrease in a specific vegetation index depends on four elements: 1) the specific vegetation index (e.g., EVI, NDVI, etc.), 2) latitude of the study site, 3) viewing geometry of the sensor (e.g., fixed or variable), and 4) conditions such as cloud cover or data compositing methods that influence the likelihood of surface observations when the instruments are observing in the principal plane. Careful characterization and correction of similar artifacts in data from other remote sensing platforms is therefore critical to isolate subtle seasonal changes in vegetation properties.